A Circumpolar ENVISAT ASAR GM map of backscatter statistics for utilisation of global soil moisture datasets

VIENNA UNIVERSITY OF TECHNOLOGY
DEPARTMENT OF GEODESY AND GEOINFORMATION
RESEARCH GROUPS PHOTOGRAMMETRY & REMOTE SENSING

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Circumpolar ENVISAT ASAR GM map of backscatter statistics: The 'Scaling Layer'

Idea of a scaling layer was developed within the ESA DUE SHARE project - for Southern Africa (Sabel et al. 2007)

Revisited now within the PAGE 21 *(Changing Permafrost in the Arctic and its Global Effects in the 21st Century)* project (circumpolar data have been reprocessed).

Part of the Work Package 5 (WP5) on Remote sensing and multi-scale integration.

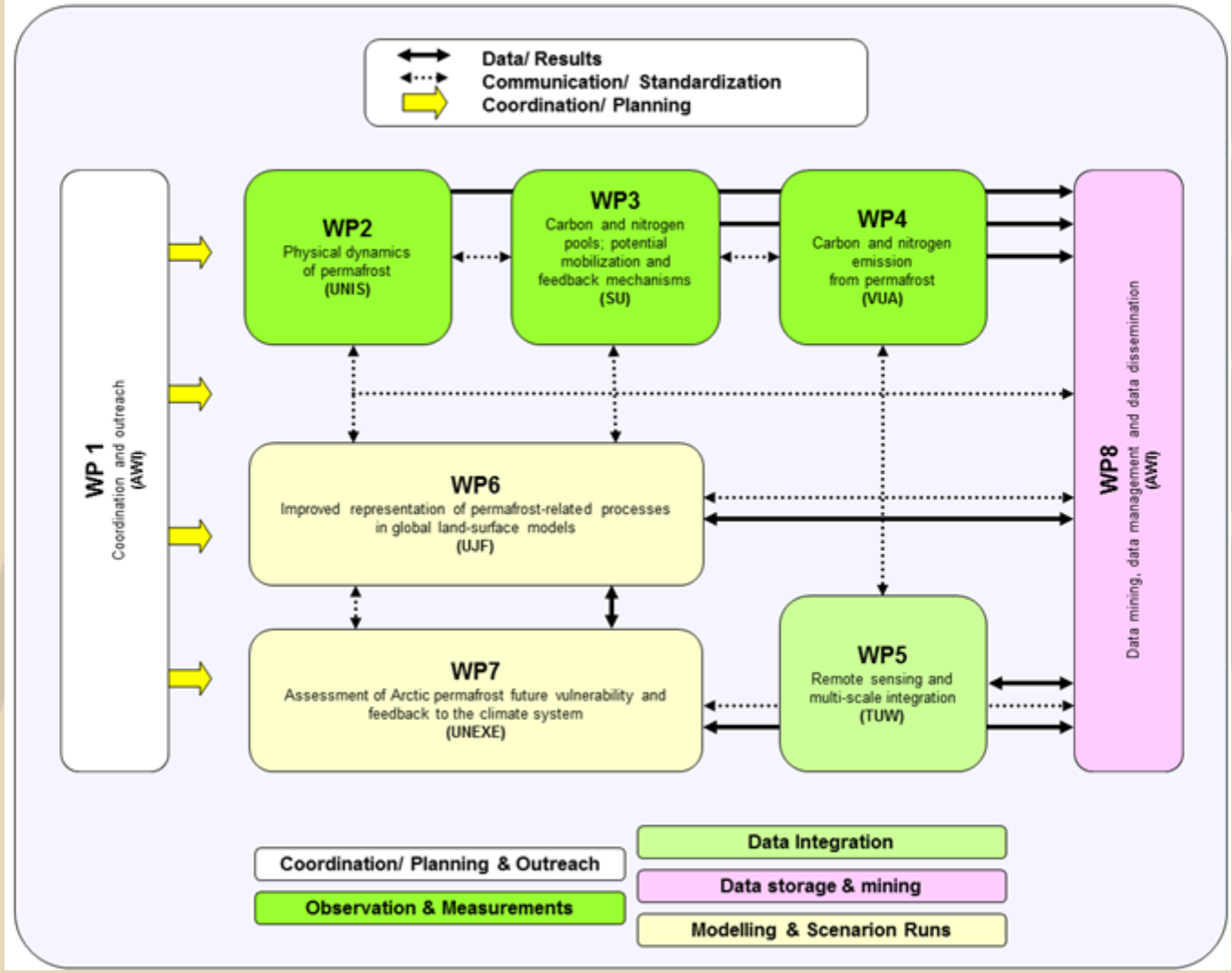
PAGE21 – the vision

PAGE21 aims to understand and quantify the vulnerability of permafrost environments to a changing global climate, and to investigate the feedback mechanisms associated with increasing greenhouse gas emissions from permafrost zones.

PAGE21 combines field measurements of permafrost processes, pools, and fluxes, with remote sensing data and global climate models at local, regional and pan-Arctic scales in order to improve global numerical permafrost modeling

The project

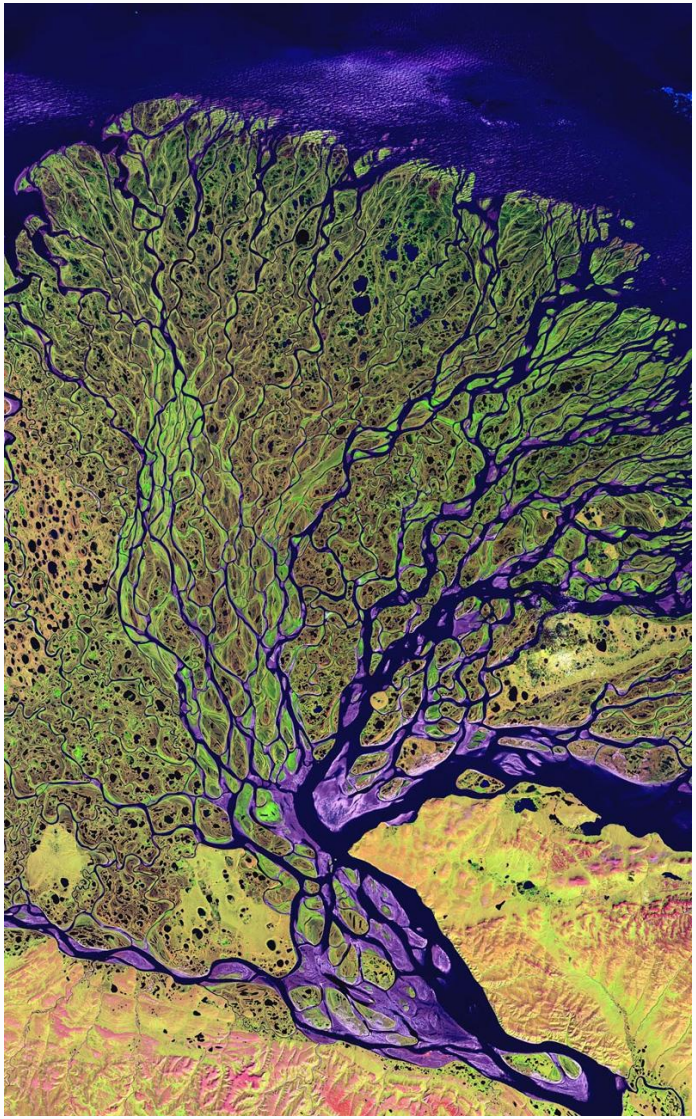
PAGE21



WP5 Remote sensing

Leader: A. Bartsch (TUW, Austria)

- Provision of improved land surface information to models
- Develop and integrate circumpolar-applicable downscaling schemes for land surface temperature, soil moisture and wetland dynamics
- Carry out coordinated detailed in situ remote sensing site investigations in order to allow model validation and for assessment of site representativeness for upscaling and circumpolar comparability.
- Enable upscaling by integrated analyses of the land surface with respect to dynamics and land surface heterogeneity.



WP5 Objectives

- To support modelling and process studies by provision of improved land surface information addressing the specific lack of information on arctic environments. Specifically:
  - To develop and integrate circumpolar-applicable downscaling schemes for land surface temperature, soil moisture and wetland dynamics, complementing existing monitoring schemes.
  - To carry out coordinated detailed remote sensing site investigations in order to allow model validation and for assessment of site representativeness for upscaling and circumpolar comparability.
  - To enable upscaling by integrated analyses of the land surface with respect to dynamics and land surface heterogeneity.

Land-surface hydrology

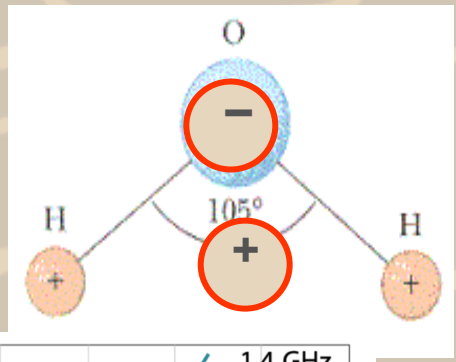
- Surface soil moisture (SSM)
  - –soil moisture influences heat transfer
  - –Indicative for drainage conditions
- Lakes (water bodies - WB)
  - –Indicative for thermokarst processes, permafrost degradation
- State transition (freeze/thaw timing – FT; surface state flag - SSF)
  - –Complements land surface temperature
  - –Can serve as masking input for SSM

Surface Soil Moisture from satellite data

- Optical to Mid-Infrared (0.4 – 3 μm)
  - Change of “colour”
  - Water absorption bands at 1.4, 1.9 and 2.7 μm
- Thermal Infrared (7-15 μm)
  - Indirect assessment of soil moisture through its effect on the surface energy balance
  - Thermal inertia
    - The resistance of a material to temperature change, indicated by the time dependent variations in temperature during a full heating/cooling cycle (a 24-hour day for Earth)
    - Function of heat capacity and thermal conductivity
- Microwaves (1 mm – 1 m)
  - Change of dielectric properties

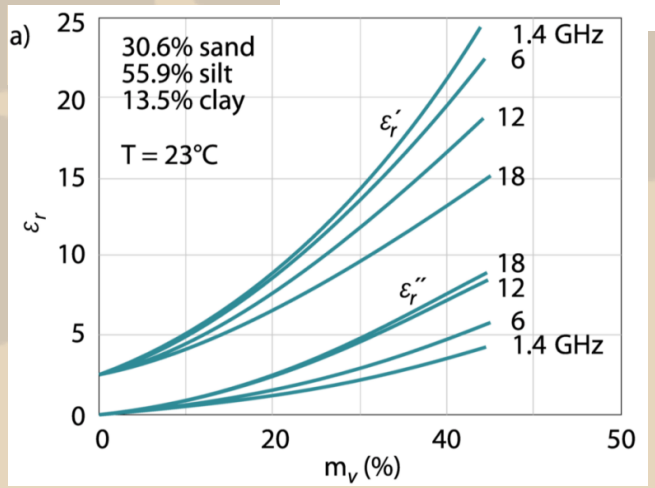
Microwave Remote Sensing of Soil Moisture

- Water is unique amongst naturally abundant materials because of its electric dipole
- Dielectric constant increases with soil moisture



Microwaves (1 mm – 1 m) are highly sensitive to soil water content

- The relationship between backscatter and soil moisture is almost linear (Ulaby et al. 1982)
- All-weather, day and night measurement capability
- Penetrate vegetation and soil to some extent (penetration depth increases with wavelength)



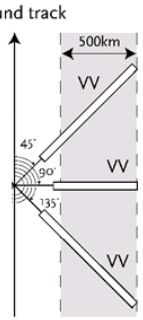
- Passive and active methods are interrelated through Kirchhoff's law: e = 1 – r

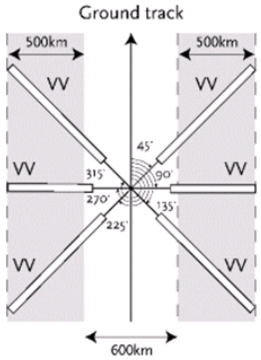
Used active microwave sensors

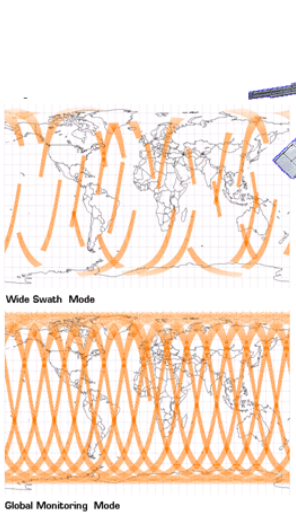
ERS Scatterometer
- 1991 up to present
- 3 antennas
- 50 km spatial resolution
- Daily coverage < 41 %
- 5.3 GHz
- VV Polarisation
- Swath width: 500 km

METOP Advanced Scatterometer
- launched in October 2006
- 6 antennas
- 5.3 GHz, VV Polarisation
- Swath width: 2 x 550 km
- Resolution: 50 / 25 km
- Daily coverage ~ 80%

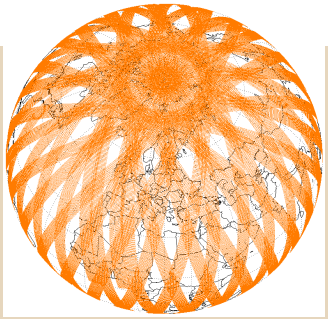
ENVISAT ASAR
- 2003 up to 2012
- Global Mode: 1km
- Wide Swath Mode: 150 m
- 5.3 GHz, VV Polarisation
- Swath width: 405 km







Theoretically possible daily coverage



- algorithms have been successfully applied outside of polar regions in the past,
- available at multiple scales
- Continuity
- operational monitoring possible

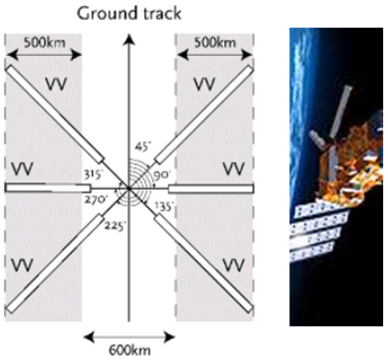
ASCAT

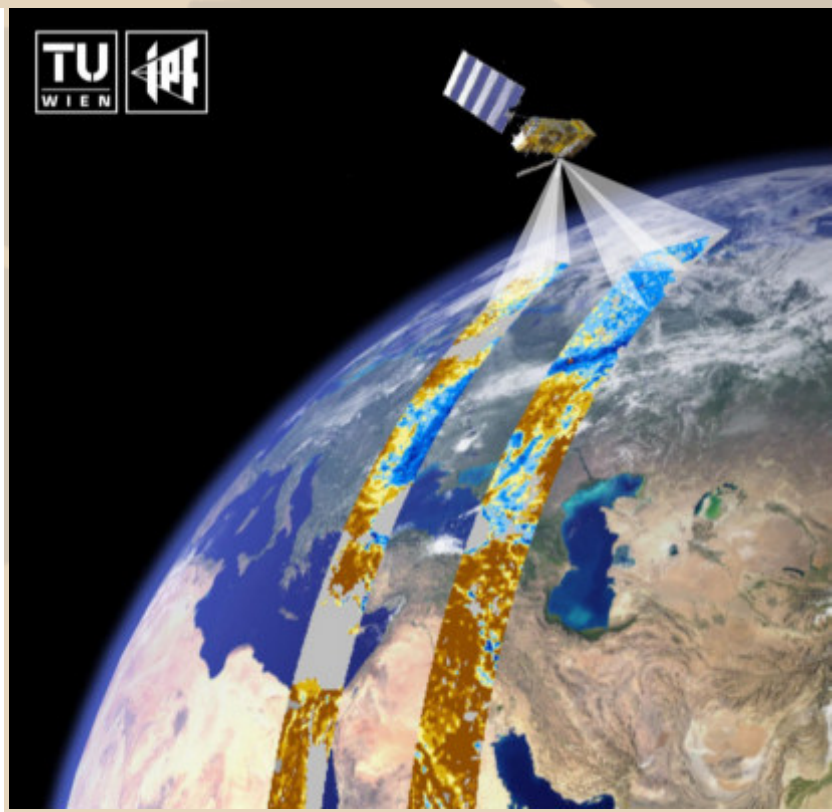
- Advanced scatterometer (ASCAT) onboard Metop
- Two 550 km swaths

- ASCAT soil moisture product

METOP Advanced Scatterometer

launched in October 2006
6 antennas
5.3 GHz, VV Polarisation
Swath width: 2 x 550 km
Resolution: 50 / 25 km
Daily coverage ~ 80%

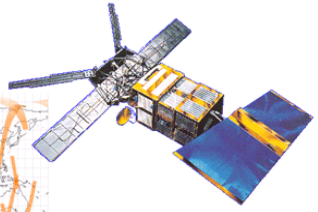


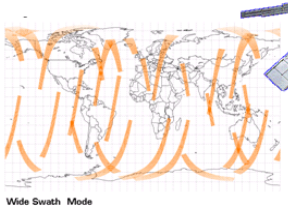


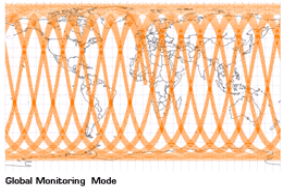
ENVISAT ASAR

ENVISAT ASAR

2003 up to p 2012
Global Mode: 1km
Wide Swath Mode: 150 m
5.3 GHz, VV Polarisation
Swath width: 405 km

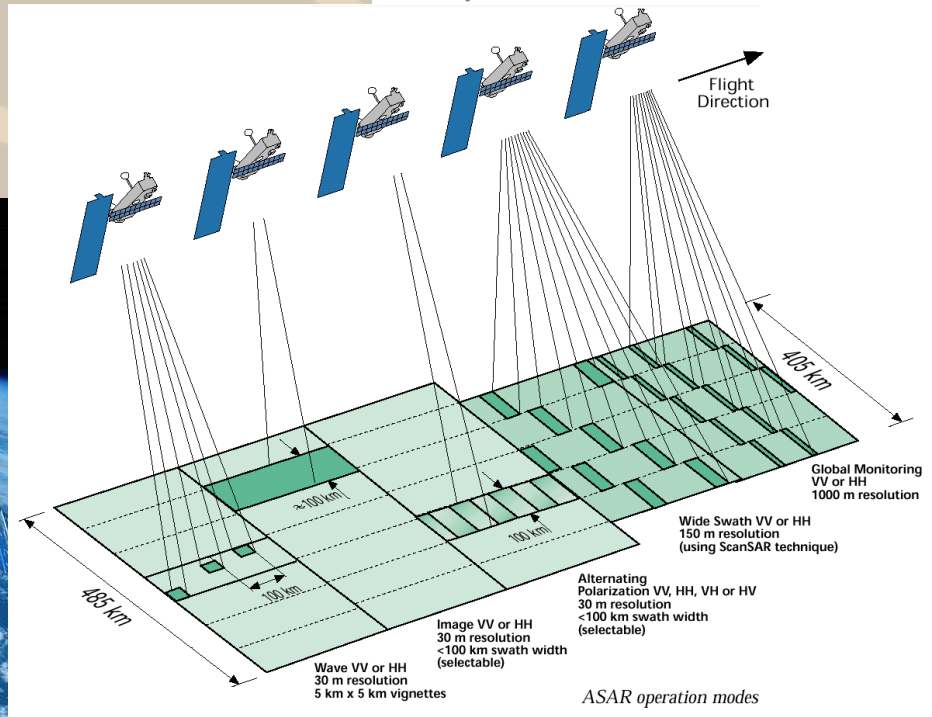






Theoretically possible daily coverage

- C-Band (5,3 GHz)
- 5 modes
- Global Monitoring Mode (ScanSAR)
  - Background mission
  - Swath width 405 km
  - Spatial resolution 1 km

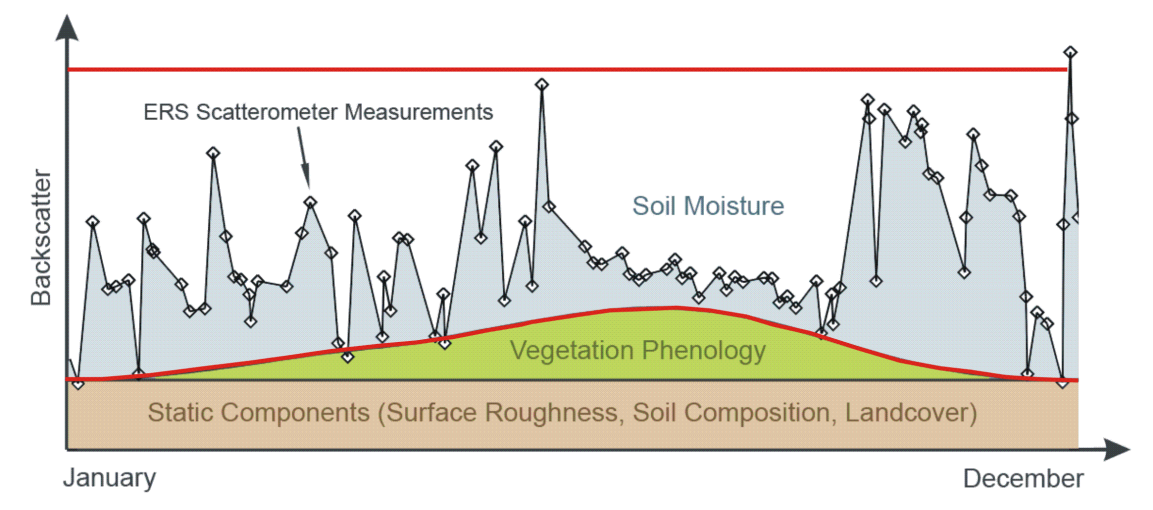


ASAR operation modes

TU Wien SSM Retrieval Algorithm

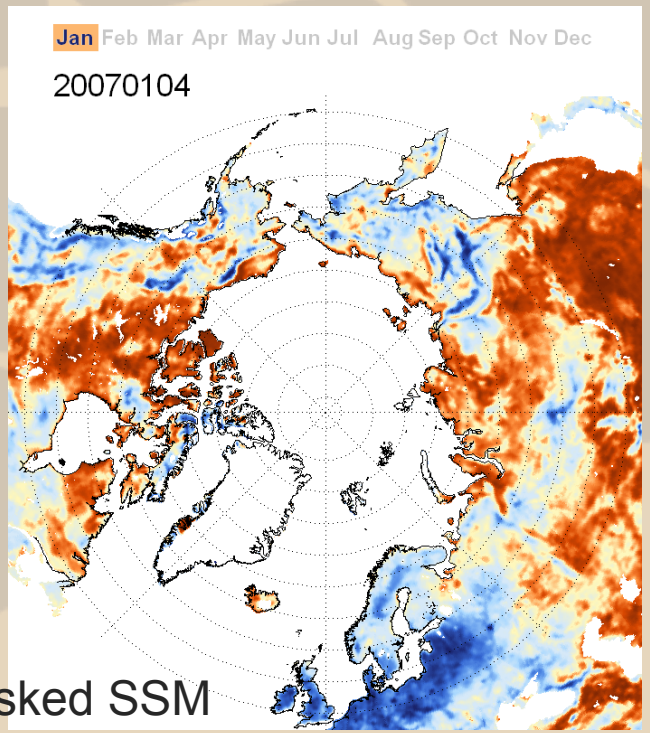
- Backscatter signal variation over time is affected by:
  - Roughness, vegetation, soil moisture and freeze/thaw status

- Change Detection Method (Wagner et al. 1999)
  - Accounts indirectly for surface roughness and land cover heterogeneity
  - Long-term time series of backscatter are needed – 20 year record available from ERS1/2



Scatterometer SSM Products

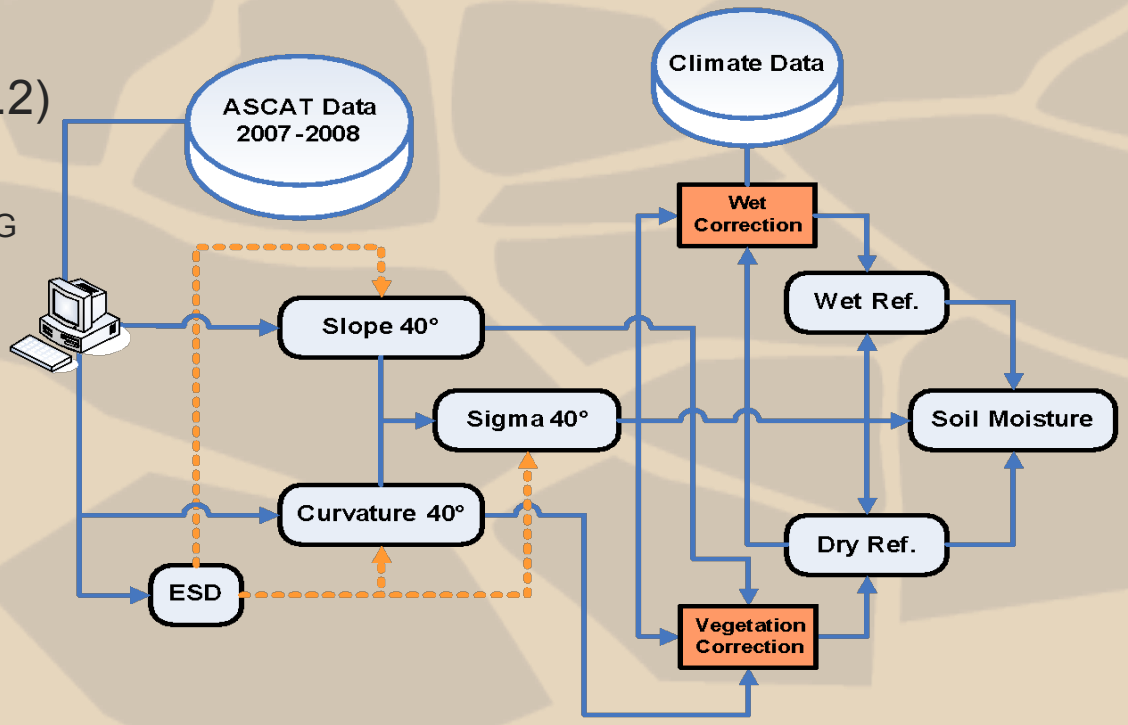
- Data are derived from METOP ASCAT measurements
- Weekly mean images in GeoTIFF format
- EASE Grid, latitudes > 50°N
- Parameters:
  - Surface Soil Moisture (SSM)
    - Unit: 0 – 100% (soil pore saturation)
    - Near surface layer (<5 cm)
  - Surface State Flag (SSF)
    - Frozen/unfrozen surface
- 25 km resolution
- Time span: 2007 – current



Unmasked SSM

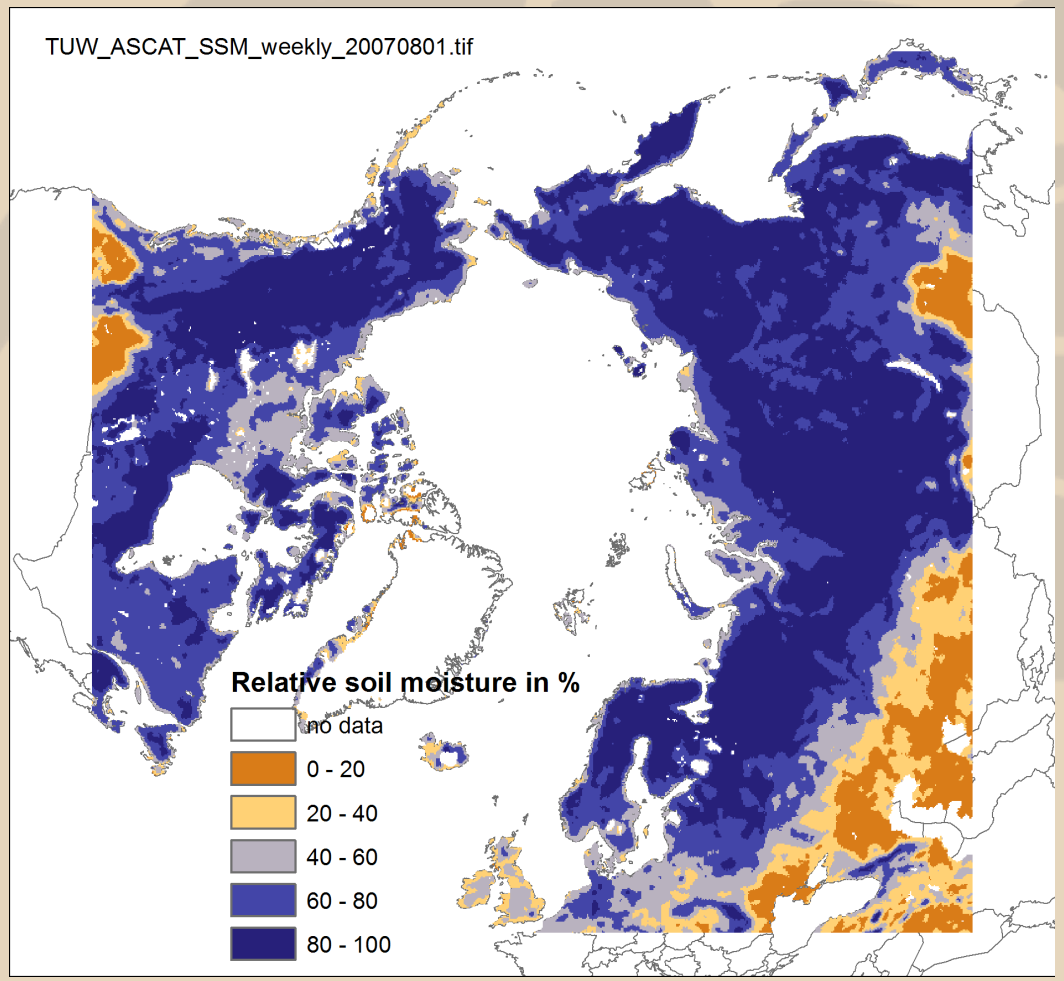
TU Wien SSM Retrieval Algorithm

- Processing Algorithm (WARP5.2)
  - Time series analysis
    - Resampling of ASCAT data to DGG
    - Azimuthal anisotropy correction
    - Normalization of backscatter
    - Dry/Wet references determination
    - Vegetation correction
    - Wet reference correction
    - Uncertainty propagation



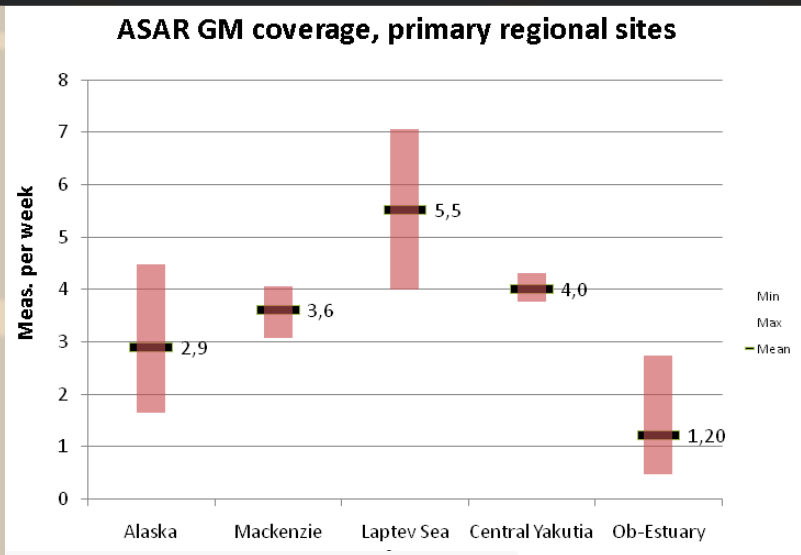
- Adaption
  - Conversion to EASE Grid
  - Weekly averaging
  - Masking for frozen ground conditions -> further development in ESA STSE ALANIS Methane project: Frozen and/or snow covered, melting snow or inundation, unfrozen

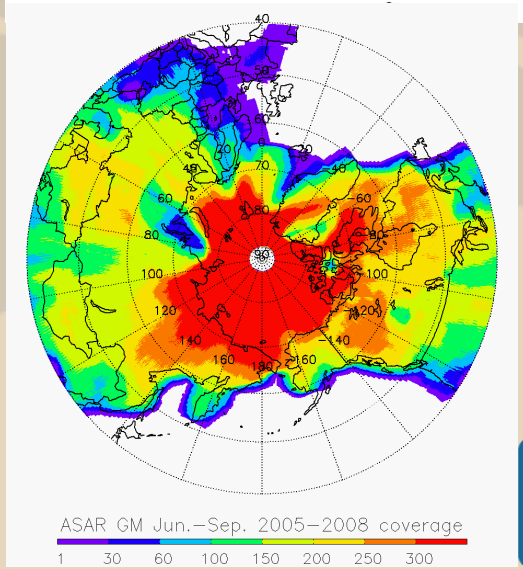
SSM product in DUE Permafrost



Transfer of algorithms to SAR for regional service

- Relative surface soil moisture algorithm can be transfered to SAR in case of sufficient data coverage
- Freeze/thaw detection requires sufficient data coverage and low noise
- Relatively good coveraged is available form ENVISAT ASAR operation in Global mode, but noise is high
- TU Wien SAR Geophysical Parameters Retrieval Toolbox (Sabel et al. 2012) available for preprocessing





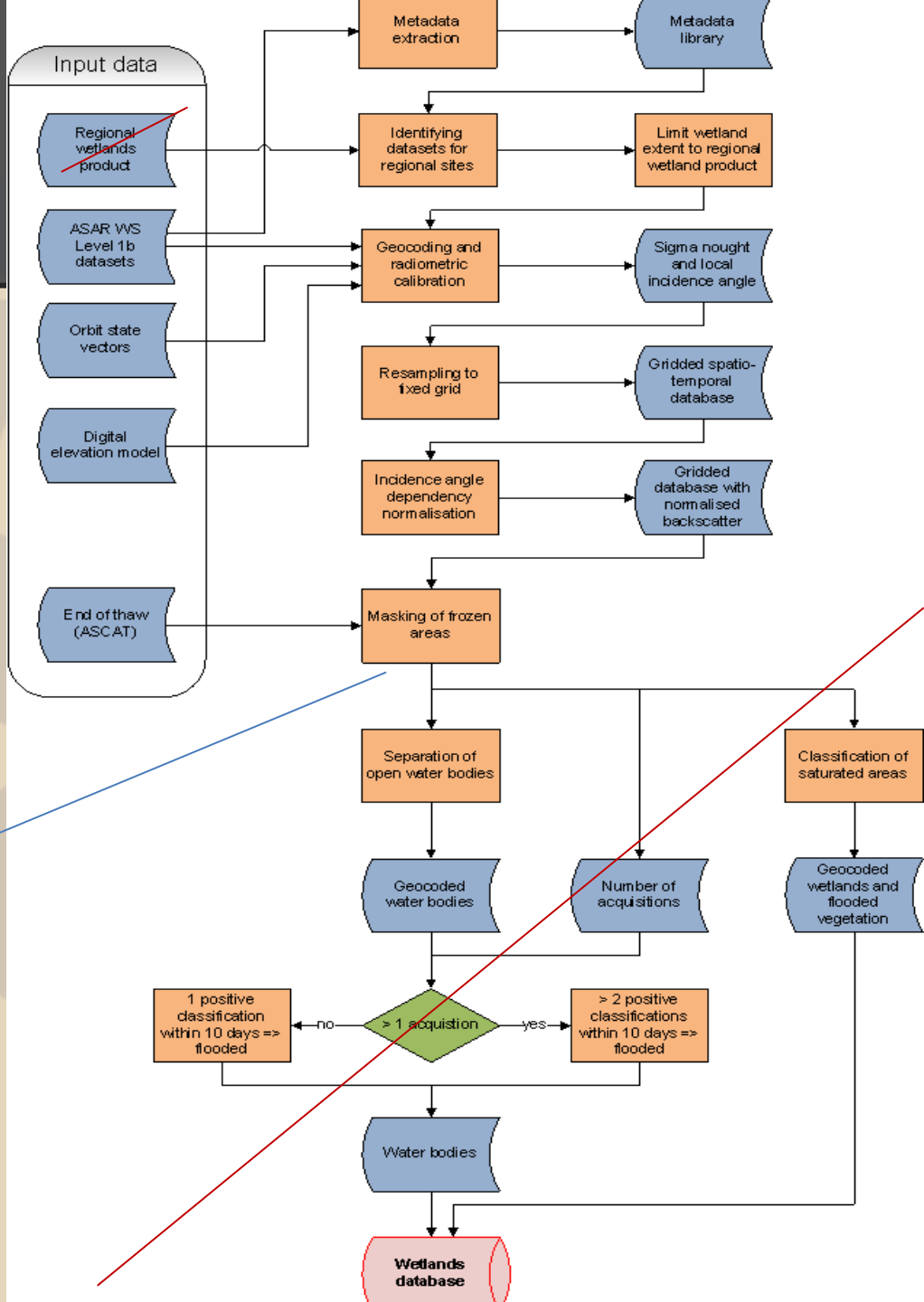
Transfer of algorithms to SAR for regional service

- For application at high latitudes the following adjustments to the algorithm have been implemented:
  - Processing in polar stereographic projection and storage of data. An entirely new gridding system has been setup in order to avoid oversampling and to reduce data storage (Bartsch et al. 2012).
  - A dry reference (representing wilting point) correction algorithm has been implemented in order to account for permanently wet areas (Bartsch et al. 2011).
  - Implementation of a post processing function for the production of weekly composites
  - Enhanced masking with respect to signal-to-noise ratio and water fraction (Sabel et al. In prep)

Transfer of algorithms

- Algorithms transferable to GM anpassen

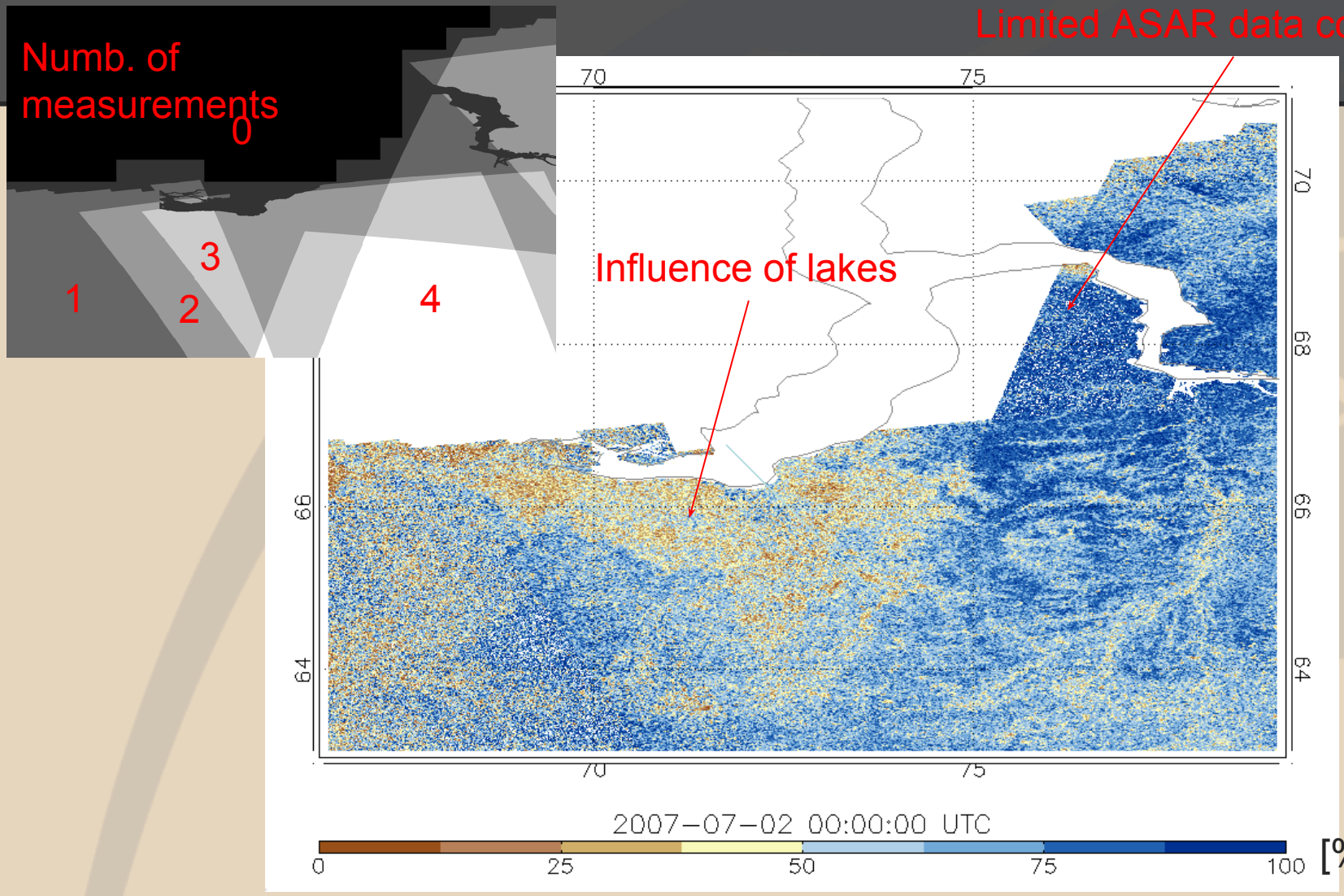
Scaling layer calculation
Masking with ASAR WS water bodies product



SAR SSM Product description

- Derived from ENVISAT ASAR GM data
- Parameter: Weekly Surface Soil Moisture (SSM)
  - Unit: 0 – 100% (soil pore saturation)
  - Near surface layer (<5 cm)
  - 1 km resolution
  - Weekly mean (subject to data availability)
  - Time span: 2006 – 2012
  - Thematic accuracy: 10-20% relative soil moisture (Pathe et al. 2009)
- Image format is GeoTiff
  - 1 x weekly mean SSM image
  - 1 x “number of measurements used” image (quality indicator)

SSM example



Ob Estuary, 2007-07-02 – 2007-07-08

Assessing the suitability of coarse resolution soil moisture from global datasets

PAGE21

Global datasets: specifically from Metop ASCAT, 25 km

Use 5 different approaches:

1. Comparison with *in situ* time series of soil moisture measurements

2. Field work to quantify spatial variability of near surface soil moisture in tundra environments and its impact on time series point comparisons (as in 1.)

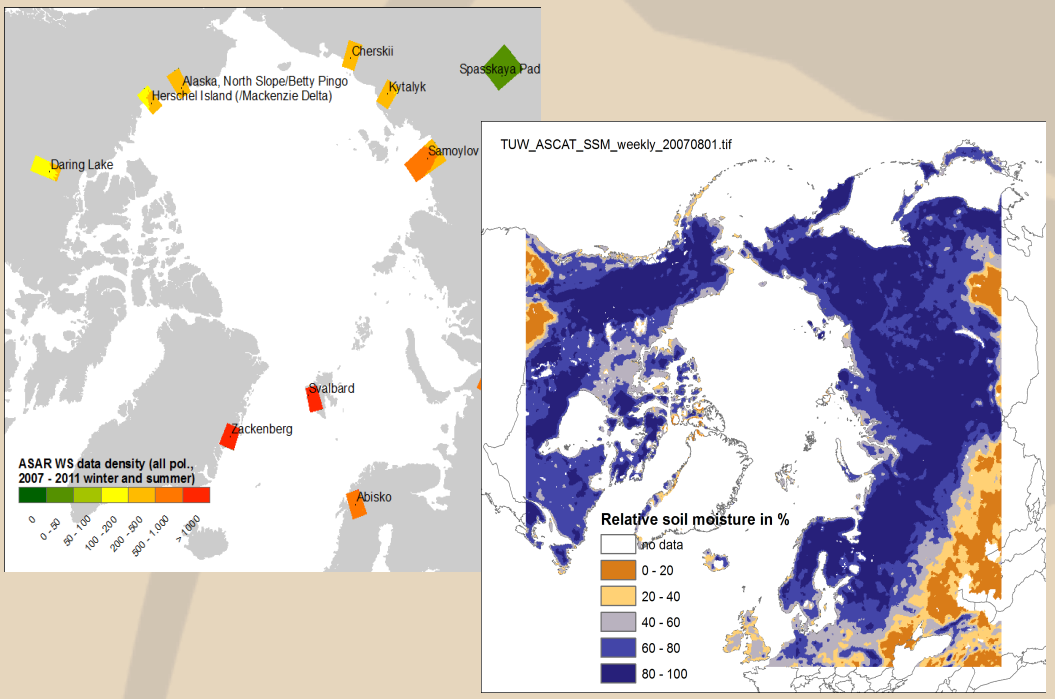
3. Retrieval of spatial backscatter correlation patterns at circumpolar extent

4. Identification of discrepancies between climate models and satellite product by WP5 (Gouttevin et al., 2013).

5. Archive analyses of SAR backscatter time series for the assessment of backscatter mechanism changes within the coarse resolution grids

Coordinated circumpolar site scale assessment

- Land surface hydrology: surface moisture and open water, complementing land cover
  - Proposed: based on multitemporal C-Band SAR
  - Allows multiscale assessment



C-Band scatterometer surface moisture

Why C-Band SAR?

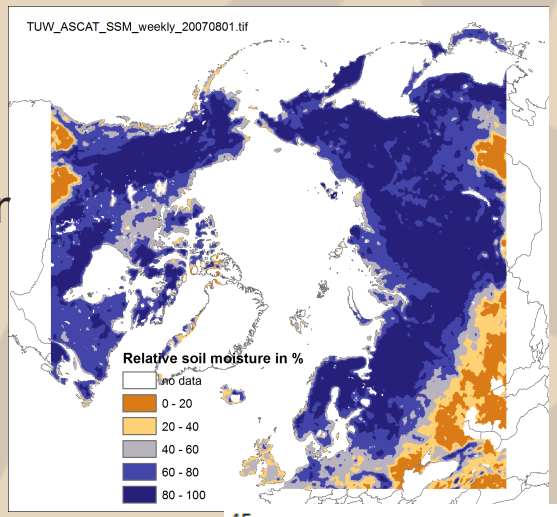
- C-Band based global soil moisture datasets available, including PAGE21 project period
- Site scale analyses can be tied in with circumpolar assessment
- Wetness classes can be derived

Coordinated circumpolar site scale assessment

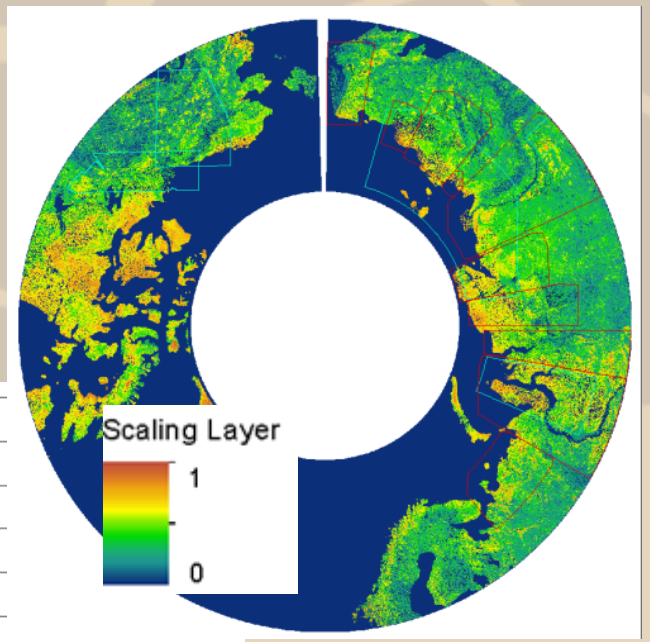
PAGE21

- Circumpolar – medium to coarse resolution

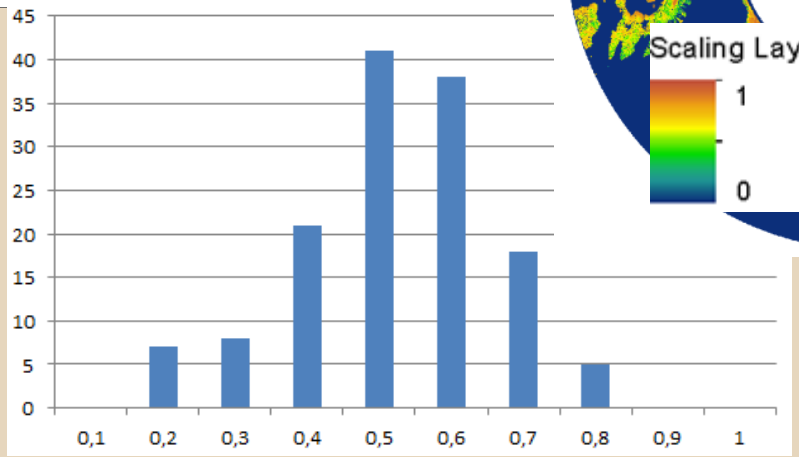
C-Band scatterometer surface moisture 2007 – 25km



ENVISAT ASAR GM: 1 km and 25 km



Histogramm of R^2 of local and regional backscatter variations (25km) for all GTN-P sites north of 55°N



TU WIEN

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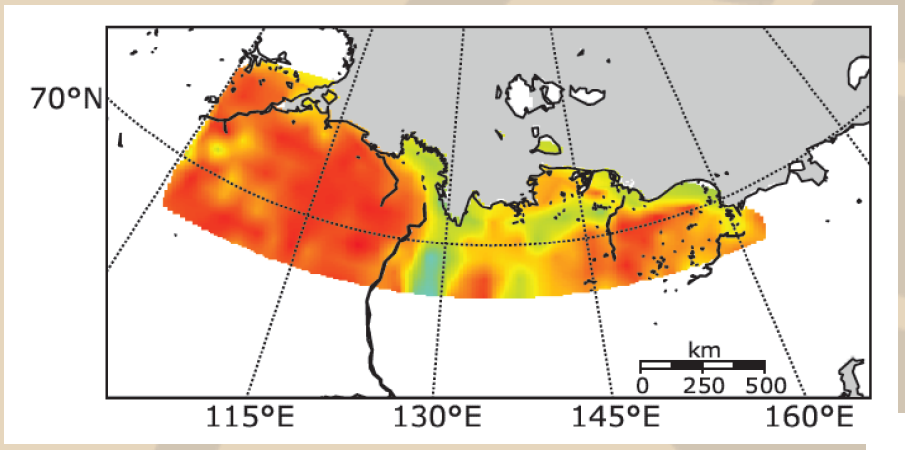
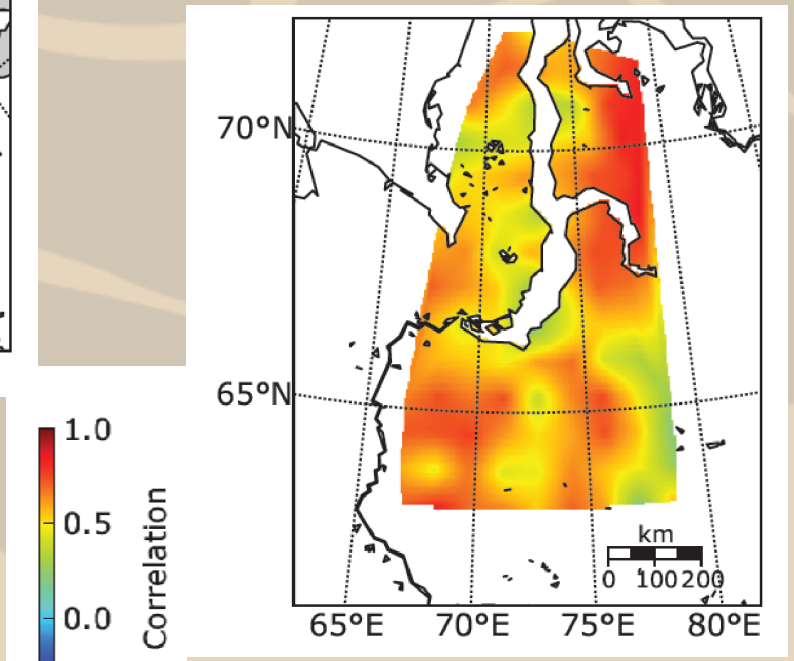
Cross-comparison

- ASAR (unmasked) – ASCAT soil moisture





Scaling Layer

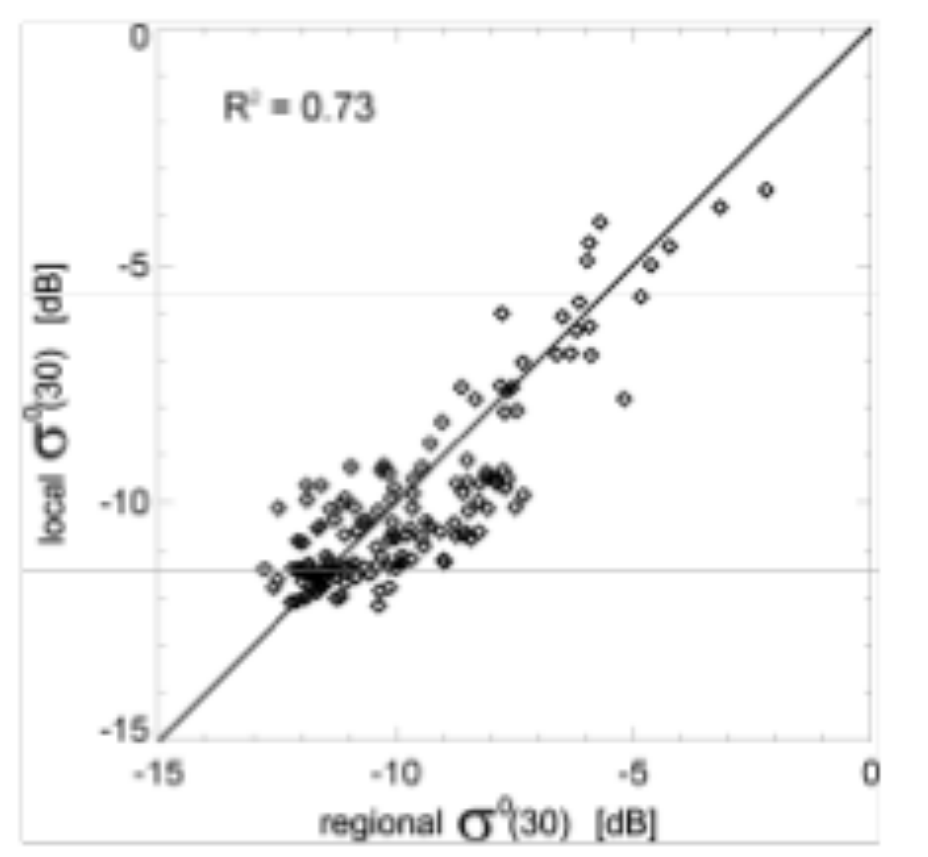
- Approach: Temporal stability according to Wagner et al. (2007)
  - Hypothesis:

    local and regional soil moisture correlated

    If high correlation then coarse resolution measurements are applicable on local scale
  - Correlation:
    - set of local (1km) backscatter values and a set of simultaneous regional (25km) backscatter extracted from time series
    - regional backscatter

      $\Rightarrow$ averaging the backscatter over rectangular window
  - Result:
    - coefficient of determination (R^2, square of Pearson correlation coefficient)
    - [0-1]

Scaling Layer

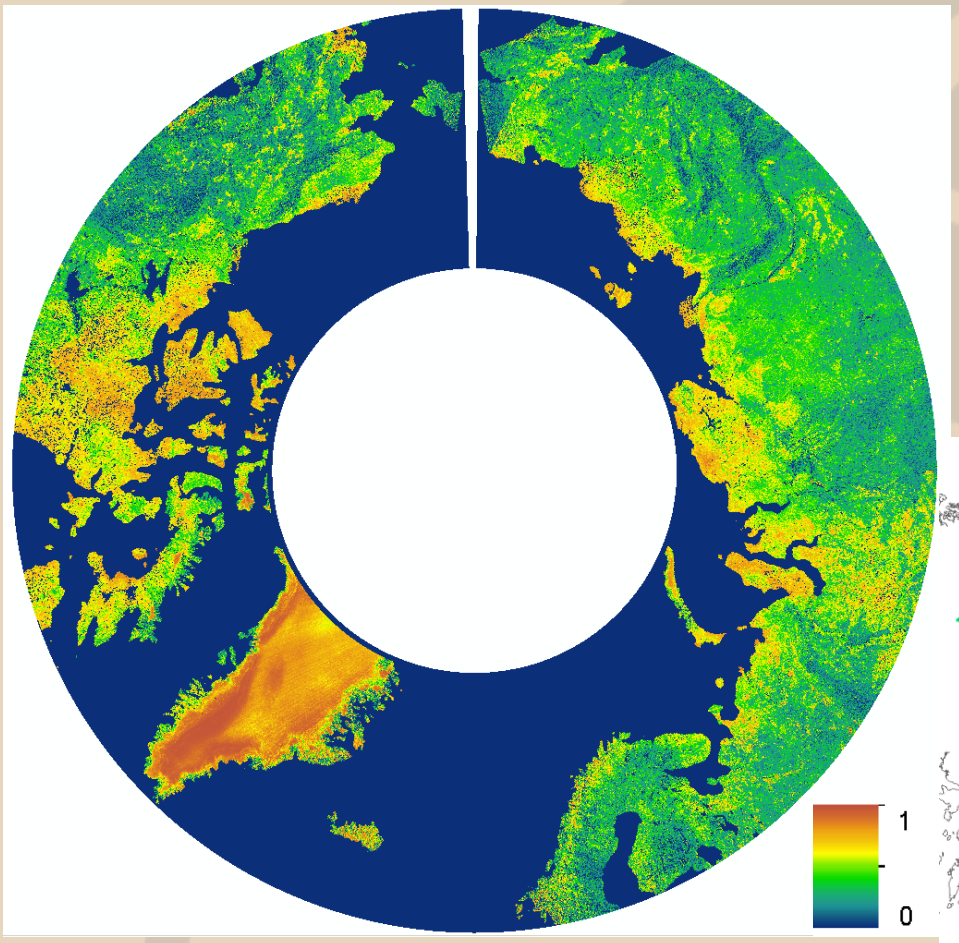


Example of scatter plot between regionally averaged backscatter and local backscatter (Sabel et al. 2007)

The scaling layer is an image consisting of the coefficient of correlation (R^2).

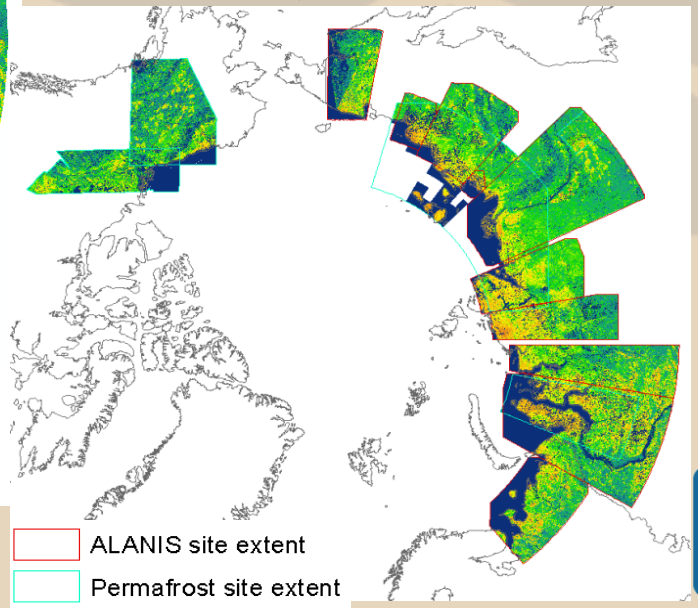
Each grid location gives a measure of the fraction of backscatter variation on the local (SAR) scale explained by the backscatter variation on the regional (scatterometer) scale.

Scaling Layer



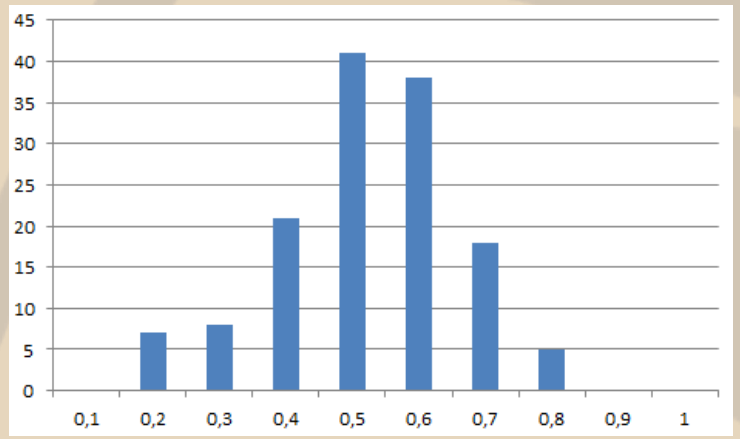
Scaling layer based on ENVISAT ASAR GM (R^2 of local and regional backscatter)

- Impact of landscape heterogeneity specifically with respect to abundance of small lakes
- Masking scheme for areas where C-Band higher resolution SAR (ASAR WS 125m) is available has been developed (Sabel et al. 2012)



Scaling Layer

- The majority of GTN-P sites north of 55°N is characterized by $R^2 > 0.5$
- This database is the key dataset for downscaling as well as upscaling of surface wetness



Abisko	0.53
Kurunagh	0.67
Kytalyk 4_06	0.71
Cherskii	0.34
Spasskaya	0.39
Daring Lake	0.65
Deadhorse	0.67
Tavvavuoma	0.71

Histogramm of R^2 of local and regional backscatter variations (25km) for all GTN-P sites north of 55°N and values for selected sites

Scaling Layer - Summary

- The Scaling Layer first introduced by Sabel et al. (2007) has been revisited and recalculated for the circumpolar region.
- It is based on the principle of temporal stability (Wagner et al. 2007)
- It represents the temporal correlation between the backscatter intensities on a local (1 km) and a regional (25 km) scale
- Its purpose is to allow an interpretation of the scatterometer derived soil moisture estimates on the local scale.